Lake Okeechobee Action Plan

Developed by the Lake Okeechobee Issue Team
for the South Florida Ecosystem Restoration Working Group

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Table of Contents

Lake Okeechobee Restoration Action Plan

Executive Summary

Overview of the Problem

The Lake Okeechobee Issue Team was formed in May 1998 by the South Florida Ecosystem Restoration Working Group. The charge given to the Issue Team is development of an Action Plan to protect and enhance the ecological and societal values of Lake Okeechobee. The primary focus of the Action Plan is on reducing in-lake concentrations of total phosphorus to 40 ppb, the goal of the SWIM Act. The Action Plan represents a consensus of federal, state, and local representatives involved in management of the lake, as well as representatives of regional municipalities, and concerned citizens. The Plan describes actions that could improve both water quality and lake ecosystem functions (e.g., fish and wildlife habitat).

The major components of this plan were developed in the context of the following key factors: (a) Phosphorus loads to the lake greatly exceed the total maximum load considered acceptable by the scientific community for sustaining a healthy ecosystem. (b) The excessive phosphorus loads are attributable to human activities in the watershed, in particular animal agriculture. (c) If the sources of these loads are controlled, residual phosphorus in the watershed still may considerably delay reductions in tributary loads. (d) Substantial reductions in tributary loads will not result in reductions of phosphorus in the lake because of high internal loading from sediments.

Major Recommendations

Lake Okeechobee's internal and external phosphorus loads are integrally linked. Both must be addressed if the lake is to reach the 40 ppb in-lake phosphorus goal within the next century. The following set of major recommendations reflect this fact.

RECOMMENDATION – Construct Regional RaSTAs to Reduce Phosphorus Loads.
Construct, as expediently as possible, large reservoir-assisted stormwater treatment areas (RaSTAs) in the tributary basins with very high rates of phosphorus loading. The highest priority basins are S-191, S-154, and pools D and E of the Lower Kissimmee River. Once operational, RaSTAs in these locations are expected to reduce total phosphorus loading to the lake by over 100 tons / year. Additional RaSTAs, with possible locations in the Fisheating Creek and the S-71 basins, could reduce loads by an additional 70 tons / year.

RECOMMENDATION – Intensify Control of Phosphorus Sources. Determine the relative contribution of phosphorus from all sources in the Lake Okeechobee watershed and, based upon this information, identify and establish priorities for implementing the most cost-effective methods of phosphorus reduction. Source identification should include all agricultural, urban, and residential areas, sludge and animal waste disposal sites, and sources of phosphorus outside the SWIM planning area, in particular the Upper Kissimmee Chain-of-Lakes and Lake Istokpoga. All management strategies and programs must be fully integrated to assure compliance with the Total Maximum Daily Loads (TMDLs).

RECOMMENDATION – Control Internal Phosphorus Loading. Phosphorus-rich mud sediments need to be removed from the lake to the maximum extent that is practical, in order to reduce internal phosphorus loading. Unless this internal loading is substantially reduced, it may take as long as 100 years for the lake to respond to watershed phosphorus control programs.

RECOMMENDATION – Conduct programs to control exotic and native plants and minimize the occurrence of damaging high water levels. There must be an aggressive program to eliminate torpedograss from the lake's littoral zone, and continuation of ongoing efforts to eradicate melaleuca. An overall plan for management of exotic and native plant communities in the lake is needed. Actions should be taken to reduce the occurrence of damaging high lake levels. This can be accomplished by first utilizing the operational flexibility provided by the recently developed WSE lake regulation schedule, and then to a much greater extent by construction of regional water storage facilities (large reservoirs and ASR wells) of the C&SF Restudy.

These programs will require a long-term commitment by land-owners, resource management agencies, and other government officials. Due to the serious nature and magnitude of the problems facing the lake, these recommendations should be quickly implemented.

Background

Lake Okeechobee, with an area of 730 square miles and a drainage basin of 5,000 square miles, occurs at the center of the inter-connected Everglades ecosystem, which includes the Kissimmee River to the north and the Everglades Protection Area (EPA) to the south. Due to its central location, water quality in the lake influences not only its own biological communities, but also the natural communities located downstream (the EPA and east & west coast estuaries), which receive water from the lake.

Under natural historic conditions, Lake Okeechobee was a direct source of water to the Everglades. Water exited the lake after periods of heavy rainfall by way of numerous small tributaries, as well as by a broad sheet-flow at the southeastern lake edge. At that time, the lake bottom was comprised primarily of sand with low phosphorus content. Phosphorus concentrations in the water column of the lake were near or below 40 ppb.

Water exiting the lake into the Everglades had low levels of turbidity and total phosphorus concentrations.

Conditions in and around Lake Okeechobee changed dramatically during the last century, as a result of agricultural development in the watershed to the north of the lake, and construction of the Central and South Florida (C&SF) Project. Excess nutrient inputs from agriculture and more efficient delivery of stormwater by the C&SF Project have resulted in more than a doubling of in-lake total phosphorus concentrations (Figure 1).

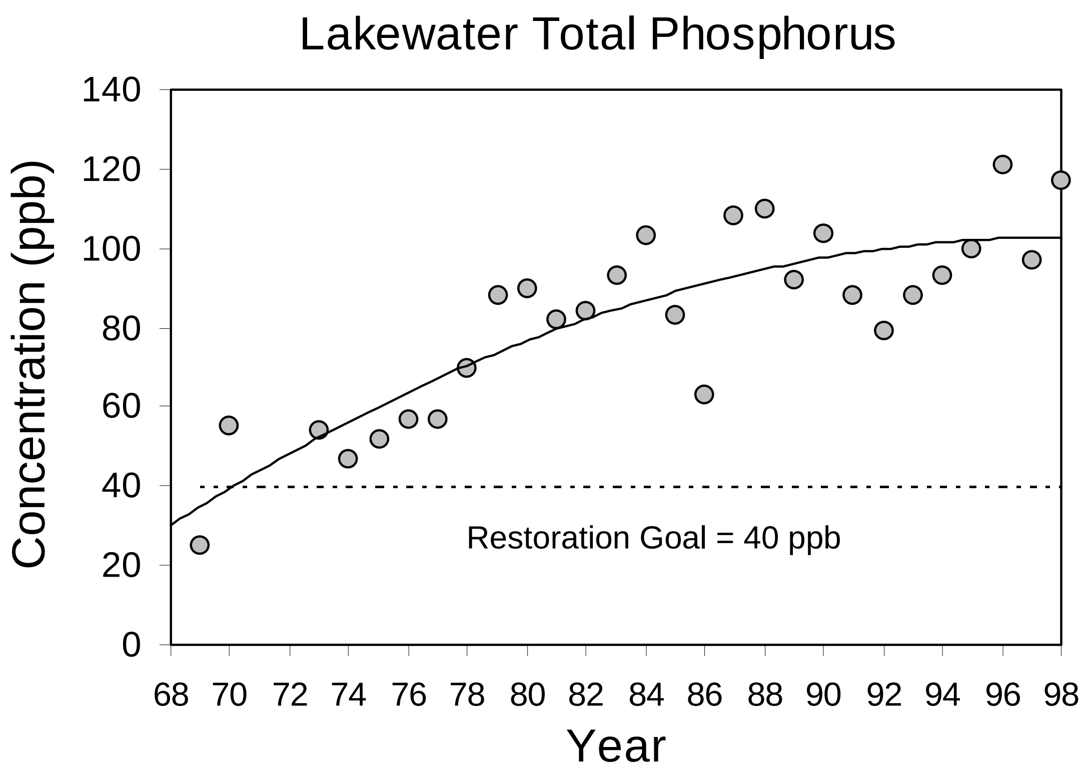

Figure 1. Yearly average total phosphorus concentrations in the open-water (pelagic) region of Lake Okeechobee. Data from 1973-1998 are based on data collected at eight long-term monitoring stations by the SFWMD. Data from 1969-1970 were collected by the US Geological Survey at eight similarly located stations (Joyner 1974). The 40 ppb goal is based on the SWIM Act and SFWMD Technical Publication 81-2.

This increase in phosphorus has shifted the natural balance of nutrients in the lake, led to conditions that are favorable for blooms of undesirable blue-green algae, and contributed to the accumulation of phosphorus-rich mud sediments over an extensive area of the lake bottom. Operation of the C&SF Project for regional flood control has resulted in prolonged periods of high water levels in the lake. This situation has exacerbated the lake's phosphorus problems, damaged near-shore plant beds, and possibly contributed to the expansion of cattail in the near-shore region of the lake's littoral zone. The C&SF Project also included the construction of large canals linking Lake Okeechobee to the St. Lucie and Caloosahatchee estuaries. The discharge through these canals has severely impacted both estuaries.

Management Issues and Restoration Strategies

The existing conditions within the lake are attributed to three major issues.

Issue*: *Watershed Phosphorus Loading

Phosphorus loading is far in excess of the amount considered acceptable for a healthy Lake Okeechobee ecosystem. Sources of phosphorus pollution in the watershed primarily are agriculture-related. Many of these sources have been regulated, and some progress was made in phosphorus load reduction between the 1980s and early 1990s. However, loads to the lake no longer are declining, and it is clear that aggressive measures are needed to substantially reduce the phosphorus loads.

***Strategies*:**

1. Construct RaSTAs to attenuate peak flows of water to the lake and to reduce concentrations of phosphorus in that water. Small scale "pilot" STAs will be constructed as the major part of the Critical Project under the Water Resources Development Act. Information on phosphorus processing by these pilot wetlands will facilitate the optimization of large-scale RaSTA systems.

2. Develop a phosphorus budget for the watershed that accounts for all imports and exports, including loading into the lake. This budget will allow for a better identification of major problem areas that should receive priority attention.

3. Review and improve existing programs to control phosphorus discharges in the watershed, to ensure that all regulated sources meet establish discharge concentration targets (Works of the District) or technology-based performance goals (FDEP Dairy Rule). Included under this strategy are: evaluation of the effectiveness of existing applied technologies and their management plans, evaluation of whether numeric discharge limits should be applied to Dairy operations, evaluation of whether existing numeric discharge limits should be modified, and re-evaluation of the methods whereby numeric discharge limits are established from loading targets and watershed assimilation coefficients.

4. Develop a plan to ensure that new land uses in the watershed do not result in increased phosphorus loads to the lake.

5. Prohibit the import of residuals (sludge) and animal manure from outside the Lake Okeechobee watershed, and evaluate the impacts of the land application of residuals and manure from within the watershed on water quality.

6. Develop and implement measures to control phosphorus inputs from tributary sources that previously (SFWMD 1997) were designated as "uncontrollable." In particular, consider measures to control phosphorus discharges from the Upper Kissimmee Chain-of-Lakes and Istokpoga, because those discharges have increased dramatically in the last decade (from below 50 to over 140 tons/yr). At the present time it is unclear whether these increases are due to lake management programs (e.g., draw-downs) or changes in land use. The causes of the increased phosphorous loading will dictate the appropriate remedies.

7. Reclaim isolated wetlands on pasture lands in order to attenuate peak flow of water, remove phosphorus, and provide additional habitat for wildlife. This strategy is being proposed as a Critical Project under the Water Resources Development Act. There may be an opportunity to restore a substantially larger number of wetland sites than the 10 being proposed under the Critical Project.

8. Implement additional management practices on beef cattle ranches that maximize phosphorus reduction, based on results from the ongoing Agroecology Research Project and recommendations from earlier studies (e.g., ensuring that all waterways are adequately fenced to prevent access by cattle) and the BMP document prepared by the Florida Cattlemen's Association entitled "Water Quality BMPs for Cow-Calf Operations in Florida."

9. Evaluate, and implement if feasible, sediment traps in tributaries, coupled with periodic removal of the phosphorus-rich material.

10. Evaluate whether routine cleaning of canals and ditches is a significant source of phosphorus loading to the lake. If it is, develop and implement a management plan to ensure that the cleaning does not result in large phosphorus discharges.

11. Evaluate alternative nutrient reduction treatment technologies, such as fish production facilities, based on their scientific rigor and economic viability.

12. Modify the watershed monitoring program so that it can quantify phosphorus loading at various scales, including total loading to the lake, loading from tributary basins, and loads from large land areas. The latter will be required to evaluate the effectiveness of any additional BMPs or compliance with new rules, should they be developed.

Issue*: *Internal Phosphorus Loading

Internal phosphorus loading, from sediments to the overlying water column, must be controlled or the lake will not respond in this century to reductions in the external loading.

Strategy:

1. Implement a lake sediment removal feasibility study, and if it is deemed feasible, carry out complete or partial removal of the phosphorus-rich mud sediments from the lake.

Issue*: *Littoral Vegetation and High Water Levels.

The lake’s littoral zone, which provides critical habitat for fish and wildlife (including federally endangered species), has experienced a dramatic expansion of exotic and nuisance plants that are displacing native vegetation. The near-shore region has lost most of its submerged plant community due to high water levels, and a ridge of organic material has accumulated along the western lake shore.

Strategies:

1. Develop and implement a program, using herbicide and fire, which can effectively kill dense stands of torpedograss and allow native plant communities to return to the affected areas. Prioritize the research conducted at the State’s new Invasive Exotic Aquatic Plant Quarantine facility, to include the evaluation of the use of biological control agents to kill torpedograss.

2. Continue the District’s *Melaleuca* eradication program and research in further biological controls.

3. Develop a comprehensive management plan for control of all exotic and nuisance plants within the lake.

4. Remove the berm and evaluate whether any additional management actions (e.g., replanting of native vegetation) will be needed to bring about re-establishment of submerged plant communities along the western shore.

5. Use the operational flexibility provided by the WSE regulation schedule and components of the C&SF Restudy Project to reduce the occurrence of damaging high lake levels.

LAKE OKEECHOBEE RESTORATION ACTION PLAN

I. Watershed Phosphorus Loading Issue

A. Background

The watershed around Lake Okeechobee is dominated by agricultural activities that discharge large quantities of nutrients (Anderson and Flaig 1993) and impact the ecological condition of the lake (Steinman et al. 1999). Phosphorus is of particular concern because it has been identified as the key element contributing to the lake's eutrophication (Federico et al. 1981, Havens et al. 1996a). In the early 1970s, when phosphorus concentrations were lower, the lake's algal community was phosphorus-limited and dominated by diatoms (desirable algae that do not form blooms). However, high inputs of phosphorus in the 1970s and 80s created a situation of phosphorus surplus in the lake, and switched the algae to nitrogen limitation (Havens 1995). This favored the dominance by blue-green algae that continue to proliferate, periodically causing surface blooms.

To address these problems, a phosphorus loading target was developed in the early 1980s and legally mandated in the SWIM Act (Sections 373.451 and 373.4595 of the Florida Statutes) to rehabilitate the ecological condition of Lake Okeechobee. The SWIM Act specified a 40% reduction in phosphorus loading from the rate that occurred between 1973-1979 (Federico et al. 1981). The ultimate goal is to reduce in-lake total phosphorus concentrations to 40 ppb.

The SWIM Act specified that target loads of phosphorus in any given year are to be calculated according to inflow volume and water residence time, using a modified version of the Vollenweider (1976) lake eutrophication model (Federico et al. 1981). The use of this model in a shallow lake where there is internal loading, and the validity of the target established from it, have been questioned and critically evaluated (Havens and James 1997). A more complex model that accounts for internal loading is under development (James et al. 1997). That model could be used to establish a new loading target for the lake. More information regarding phosphorous concentration goals, loading targets, and concerns about the current version of the Vollenweider model are presented in Appendix I.

B. Lake-wide Phosphorus Loading

Since 1991 the rate of phosphorus loading (5-year rolling average) has exceeded the SWIM target by over 100 tons per year (Table 1 and Figure 1). Particularly high loads have occurred during some recent years when there has been high rainfall and and associated stormwater runoff from the watershed. Even if all currently regulated lands meet their phosphorus reduction goals, loading to the lake is expected to far exceed the SWIM target. Perhaps more importantly, given that the lake now displays high internal phosphorus loading (approximately equal in magnitude to the external load), <u>the SWIM target load clearly is not adequate to achieve the in-lake goal of 40 ppb total phosphorus</u>. It is expected that the

TMDL process will result in a substantially lower phosphorus loading target for the lake. The programs recommended in this Action Plan reflect this view, and aim towards reducing phosphorus loads to well below the existing SWIM target.

The TMDL that is under development will take into account the assimilative capacity of the lake, and also account for the high internal phosphorus loading. It is being developed using results of research (Reddy et al. 1995) and the recently developed Lake Okeechobee Water Quality Model (James et al. 1997). The results of this work and other ongoing studies by the SFWMD, FDEP, and USEPA will result in the establishment of a total maximum daily load (TMDL) limit for phosphorus.

Table 1. Phosphorus loading to Lake Okeechobee, including actual yearly loads, SWIM target loads generated from the Vollenweider model, the amount of over-target loading (the difference between actual and target loads), and 5-year rolling averages for the over-target amounts. Because the Vollenweider model assumes steady state conditions (inflows = ouflows), it is not entirely appropriate to consider the yearly over-target amounts. Five-year rolling average values are more representative of actual trends in the system. Once the TMDL is established, a new table can be developed to compare loads to new (likely much lower) targets.

Year	Actual Load (Short tons / year)	Target Load (Short tons / year)	Over-target (Short tons / year)	Over-target (5-yr rolling average, Short tons)
1973	543	525	18	-
1974	917	456	461	-
1975	397	294	103	-
1976	515	314	201	-
1977	438	284	154	187
1978	741	599	142	212
1979	1064	487	577	235
1980	285	173	112	237
1981	432	153	279	253
1982	966	713	253	273
1983	727	453	276	299
1984	698	317	380	260
1985	467	233	234	284
1986	574	334	240	277
1987	581	452	129	252
1988	361	282	78	212
1989	414	210	203	177
1990	470	272	198	170
1991	526	628	-102	101
1992	461	309	152	106
1993	356	256	100	110
1994	667	542	124	94
1995	782	491	291	113
1996	249	231	18	137
1997	542	520	22	111
1998	886	510	377	166

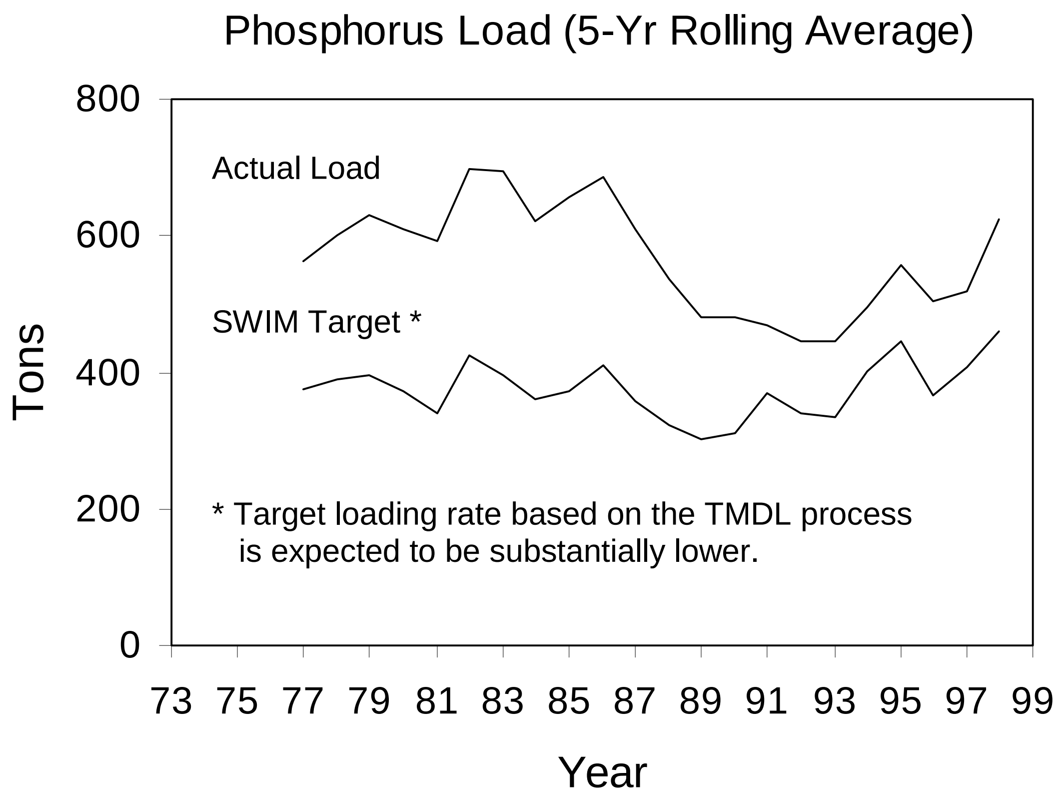

Figure 2. Phosphorus loading to Lake Okeechobee, showing the actual load and the SWIM target load. Five-year rolling averages are presented in order to smooth out the large variation that occurs from year to year, in association with variable rainfall and runoff, and provides a better picture of long-term trends in the load. Multiple-year averaging also reflects an assumption of the Vollenweider model -- that the lake is in steady state (inflows = outflows), a condition that is not satisfied on a yearly basis. Loads are in short tons.

C. Phosphorus Loading by Tributary Basin

To further understand the issues associated with excessive phosphorus loading from the watershed and potential solutions, it is important to consider sources of phosphorus at the individual tributary basin scale. The 1989 Interim SWIM Plan set phosphorus targets for each of the major tributary basins draining into Lake Okeechobee in terms of average annual, flow-weighted total phosphorus concentrations. These targets account for yearly variations in water discharge volume. To calculate the load from each basin, concentration is multiplied by flow and an appropriate conversion factor. Excess phosphorus loads may then be calculated based on the excess total phosphorus concentration (actual minus target) and the current estimation of discharge. Here we provide estimates of basin concentrations and loading rates for two periods of time, 1990-1994 (Table 2), which is the period just after full implementation of the Dairy Rule, and 1994-1998 (Table 3), representing more recent conditions. The format of these tables is identical to that presented in the most recent update of the Lake Okeechobee SWIM Plan (SFWMD 1997), except for the consideration of phosphorus loads from the basins of the Kissimmee River. Previous reports assumed that phosphorus loads from distinct basins (S-65A, B, C, D, E) could be quantified by simply subtracting loads measured at consecutive structures. The calculations often gave negative values, reflecting the fact that substantial amounts of water may flow around the structures during high flow periods, when water also can move into and through parts of the remnant channel of the original Kissimmee River. Therefore, we present only the combined amount of phosphorus loading that occurs between structure S-65 (at Lake Kissimmee) and S-65E.

Collectively, the load of phosphorus from the 39 tributary basins averaged 368 tons/yr in 1990-1994, with an excess loading (above the basin target) of 133 tons/yr. During 1994-1998 the total load was slightly higher, at 403 tons/yr. However, the excess loading was lower, at 121 tons/yr, than in the preceding period because the target loads also increased due to greater water flow volumes. During both periods considered, five basins (indicated in bold in Tables 2 and 3) had particularly high loads, totaling 272 and 302 tons/yr in 1990-94 and 1994-98, respectively. The excess phosphorus loading from these five basins averaged 118 tons/yr in 1990-94 and 102 tons/yr in 1994-98. When the TMDL is established, the excess loading amounts will need to be re-calculated. It is expected that those excess amounts will be substantially higher. As indicated above, the elements of this Action Plan recognize this fact, and aim to reduce loads to well below the SWIM target.

The highest concentrations of phosphorus (0.6 to 0.8 ppm) consistently have been found in the S-191 (TCNS) and S-154 basins. Although basin-specific loading rates cannot be determined for the individual basins along the Kissimmee River, there is an increase in the concentration of total phosphorus from S-65C to S-65-D to S-65E (0.06 → 0.08 → 0.10 ppm) that indicates sources of phosphorus in the watershed around the lower regions of the river (SFWMD 1997). All of these locations (S-191, S-154, and S-65D-E) have abundant dairy operations. They also are the locations where the greatest number of Works of the District sites are out of compliance with existing rules. If the S-191 and S-154 basins alone met their target loads, phosphorus loading to the lake could be reduced by over 80 tons/yr. When the S-65D-E basins of the lower Kissimmee River are included, there may be a potential for phosphorus load reductions of greater than 100 tons/yr.

However, it does not appear that these load reductions can be achieved solely by compliance with existing rules and regulations. This underscores the need for alternative phosphorus control measures in those basins. The S-191, S-154, and S-65D-E basins should be the primary focus of phosphorus control, as well as the S-71 and Fisheating Creek basins. In the later basin, loads do not exceed the SWIM target, but the total quantity of phosphorus that enters the lake from this source is high (>100 tons during years with heavy rainfall).

Table 2. Phosphorus loading by basin in the Lake Okeechobee watershed, for the 5-yr period from 1990 to 1994. Target concentrations are from the 1989 SWIM Plan (SFWMD 1989). Five basins that contribute particularly large loads to the lake are indicated in bold. Note: The over-target loading for S65-S65E may be underestimated (by up to 30 tons/yr) because the calculation uses 0.18 mg/L as the multi-basin target. Actual targets vary from 0.07 mg/L at the most upstream basin (S65A) to 0.18 mg/L in S65E.

Basin ***Controllable Sources***	Discharge (acre-ft)	Area (sq. mi)	Target TP (ppm)	Target Load (short tons/yr)	Actual TP (ppm)	Actual Load (short tons/yr)	Over Target (short tons/yr)
715 Farms (Culv 12A)	9,293	4	0.18	2.3	0.15	1.9	-0.4
C-40 Basin (S-72) - S68*	23,095	87	0.18	5.7	0.21	13.0	7.3
C-41 Basin (S-71) - S68*	52,956	176	0.18	13.0	0.19	**29.9**	**16.9**
S-84 Basin (C41A) - S68*	47,477	180	0.10	6.5	0.07	9.3	2.9
S-308C (St. Lucie-C-44)	89,043	190	0.18	21.8	0.15	18.4	-3.4
Culvert 10	7,973	10	0.18	2.0	0.48	5.5	3.5
Culvert 12	11,958	13	0.13	2.1	0.19	3.1	1.0
Fisheating Creek	178,676	462	0.18	43.7	0.16	**38.9**	**-4.8**
Industrial Canal	22,210	23	0.18	5.4	0.11	3.3	-2.1
L-48 Basin (S-127)	13,267	32	0.18	3.2	0.26	4.4	1.2
L-49 Basin (S-129)	8,595	19	0.18	2.1	0.13	1.6	-0.5
L-59E	5,640	15	0.16	1.2	0.23	1.8	0.6
L-59W	7,334	15	0.16	1.6	0.17	1.8	0.2
L-60E	1,097	6	0.10	0.1	0.15	0.2	0.1
L-60W	374	6	0.10	0.1	0.13	0.1	0.0
L-61E	6,007	22	0.09	0.7	0.14	1.2	0.5
L-61W	9,135	22	0.09	1.1	0.10	1.3	0.1
TCNS (S-191)	108,825	188	0.18	26.6	0.62	**91.5**	**64.8**
S-131 Basin	7,965	11	0.15	1.6	0.10	1.1	-0.5
S-133 Basin	24,248	40	0.18	5.9	0.25	8.3	2.4
S-135 Basin	21,557	28	0.16	4.7	0.10	2.9	-1.8
S-154 Basin	19,550	37	0.18	4.8	0.80	**19.4**	**14.6**
S-2	31,424	166	0.16	6.8	0.23	9.8	3.0
S-3	5,904	101	0.15	1.2	0.19	1.4	0.2
S-4	17,766	66	0.18	4.3	0.15	4.2	-0.1
S65E - S65 (All Basins)	265,193	749	0.18	64.9	0.25	**91.9**	**27.0**
S-236	3,407	15	0.09	0.4	0.12	0.5	0.1
Culvert 4A	7,195	7	0.08	0.8	0.12	1.2	0.4
Culvert 5	3,128	28	0.06	0.3	0.06	0.3	0.0
Controllable Totals	**1,010,290**			**235.0**		**368.1**	**133.1**
Uncontrollable Sources							
Rainfall					0.03	71.0	
S65 (Lake Kissimmee)	733,505				0.04	39.6	
Lake Istokpoga (S-68)	183,872				0.03	7.6	
S5A Basin	2,048				0.13	0.3	
E. Caloosahatchee (S-77)	3,616				0.24	1.2	
L-8 Basin (Culv 10A)	68,503				0.10	9.2	
Uncontrollable Totals	**991,544**					**128.8**	
Average Total Loadings						**496.9**	
Basin Target						**363.8**	
Vollenweider Target						**401.4**	
Over-Target Loads				***Concentration based***		**133.1**	
				Vollenweider		**95.5**	

Table 3. Phosphorus loading by basin in the Lake Okeechobee watershed, for the 5-yr period from 1994 to 1998. Target concentrations are from the 1989 SWIM Plan (SFWMD 1989). Five basins that contribute particularly large loads to the lake are indicated in bold. nd = no data. Note: The over-target loading for S65-S65E may be underestimated (by up to 30 tons/yr) because the calculation uses 0.18 mg/L as the multi-basin target. Actual targets vary from 0.07 mg/L at the most upstream basin (S65A) to 0.18 mg/L in S65E.

Basin *Controllable Sources*	Discharge (acre-ft)	Area (sq. mi)	Target TP (ppm)	Target Load (short tons/yr)	Actual TP (ppm)	Actual Load (short tons/yr)	Over Target (short tons/yr)
715 Farms (Culv 12A)	12,758	4	0.18	3.1	0.10	1.7	-1.4
C-40 Basin (S-72) - S68*	16,069	87	0.18	3.9	0.20	10.5	6.6
C-41 Basin (S-71) - S68*	52,768	176	0.18	12.9	0.18	**32.3**	**19.4**
S-84 Basin (C41A) - S68*	66,759	180	0.10	9.1	0.05	12.9	3.9
S-308C (St. Lucie-C-44)	41,480	190	0.18	10.2	0.13	8.9	-1.2
Culvert 10	11,612	10	0.18	2.8	0.53	9.8	7.0
Culvert 12	15,075	13	0.13	2.7	0.18	3.6	1.0
Fisheating Creek	256,761	462	0.18	62.8	0.18	**60.7**	**-2.1**
Industrial Canal	21,878	23	0.18	5.4	0.09	2.8	-2.6
L-48 Basin (S-127)	31,088	32	0.18	7.6	0.21	9.4	1.8
L-49 Basin (S-129)	0	19	0.18	0.0	0.09	2.0	2.0
L-59E	nd	15	0.16	nd	nd	nd	nd
L-59W	nd	15	0.16	nd	nd	nd	nd
L-60E	nd	6	0.10	nd	nd	nd	nd
L-60W	nd	6	0.10	nd	nd	nd	nd
L-61E	nd	22	0.09	nd	nd	Nd	nd
L-61W	nd	22	0.09	nd	nd	Nd	nd
TCNS (S-191)	116,022	188	0.18	28.4	0.57	**94.2**	**65.8**
S-131 Basin	11,992	11	0.15	2.4	0.12	1.9	-0.5
S-133 Basin	30,004	40	0.18	7.3	0.16	7.2	-0.2
S-135 Basin	30,097	28	0.16	6.5	0.10	4.3	-2.2
S-154 Basin	23,428	37	0.18	5.7	0.76	**22.8**	**17.0**
S-2	34,629	166	0.16	7.5	0.18	9.0	1.5
S-3	13,429	101	0.15	2.7	0.18	3.9	1.1
S-4	40,921	66	0.18	10.0	0.18	11.1	1.1
S65E - S65	364,526	749	0.18	89.2	0.18	**91.5**	**2.3**
S-236	9,716	15	0.09	1.2	0.10	1.5	0.3
Culvert 4A	8,954	7	0.08	1.0	0.09	1.1	0.2
Culvert 5	nd	28	0.06	nd	nd	nd	nd
Controllable Totals	**1,209,967**			**282.7**		**403.4**	**120.7**
Uncontrollable Sources							
Rainfall					0.03	71.0	
S65 (Lake Kissimmee)	1,139,602				0.08	119.4	
Lake Istokpoga (S-68)	342,212				0.04	22.4	
S5A Basin	0					0.0	
E. Caloosahatchee (S-77)	0					0.0	
L-8 Basin (Culv 10A)	60,922				0.10	8.3	
Uncontrollable Totals	**1,542,737**					**221.0**	
Average Total Loadings						**624.3**	
Basin Target						**503.6**	
Vollenweider Target						**458.7**	
Over-Target Loads					***Concentration based***	**120.7**	
					Vollenweider	**165.7**	

RECOMMENDATION – Construct Large-Scale RaSTAs (Reservoir-Assisted Stormwater Treatment Areas)

Because of the long history of phosphorus discharges from agriculture and other activities in the watershed, large pools of phosphorus now occur in the soils and tributaries north of Lake Okeechobee (Flaig and Reddy 1995). These soils and tributary sediments are expected to be a long-term source of phosphorus, even if upstream source discharges are substantially reduced. Under these circumstances the Issue Team recommends as the primary strategy for controlling excess phosphorus loading the construction of large-scale storm water treatment areas, such as those being used in the Everglades Agricultural Area. In the watershed north of the lake, typical STAs will not be sufficient to address the problem because the large land area required to capture storm water runoff is not readily available. A modified version of the STA design, incorporating a deep storage reservoir to capture runoff during peak flow periods, and a downstream STA to treat that water over a period of time thereafter, is considered the best option. These large-scale regional RaSTAs are included as project components in the C&SF Restudy. The Issue Team recommends that measures be taken to move expediently towards the construction of RaSTAs in the most highly polluted tributary basins, which are S-191, S-154, and pools D and E of the Lower Kissimmee River. Subsequently, additional RaSTAs should be considered for other basins with high phosphorus loads, including the S-71 and Fisheating Creek basins. The two wetland treatment systems that will be constructed as part of the Critical Project under the Water Resources Development Act can serve as prototypes, much like the ENR project did for the Everglades Construction Project. Information regarding performance of the Critical Projects wetland treatment areas will be used to guide the design and operations of large-scale RaSTAs.

Preliminary estimates (subject to change when a formal evaluation is conducted) of the amount of land needed for RaSTAs were made by SFWMD staff, assuming that reservoir components do not substantially reduce phosphorus concentrations, and that STAs reduce phosphorus in the manner described by Kadlec and Knight (1996). To achieve an outflow total phosphorus concentration discharge limit of 40 ppb (a reasonable estimate of what a typical STA can achieve based on performance of the Everglades Nutrient Removal Project), the approximate size of RaSTAs is estimated to be as follows:

Basin	Reservoir Size (Acres)	STA Size (Acres)	Total Size (Acres)	Inflow TP (ppm)	Inflow (ac-ft/yr)	Spillover (ac-ft / yr)
S-191	2,500	6,000	8,500	0.57	109,000	2,500
S-154	1,000	2,000	3,000	0.76	21,900	800
Pool D & E	**	**	**	0.8, 0.4	**	**
S-71	1,000	6,000	7,000	0.18	118,900	23,000
Fisheating Cr.	3,000	6,000	9,000	0.18	131,000	25,100

** as indicated in the text, better data are needed to calculate flows for these basins

An estimate cannot be provided at this time for S-65D-E, because it is not possible (using current data) to obtain an accurate estimate of those basins' water discharge volumes. Based on the land area and concentration of phosphorus in runoff water, a RaSTA on the order of 8,000 acres may be needed in that location. It also is critical to note that all of these RaSTA sizes only are rough estimates. A detailed design for RaSTAs is beyond the scope of this Plan. It would need to consider the relative costs and benefits of various combinations of reservoir and STA sizes, volumes of by-pass water that would be expected to occur with different configurations, as well as numerous other engineering, legal, economic, and ecological issues. Nevertheless, we can roughly estimate the amount of phosphorus load reduction that might be achieved if RaSTAs were constructed in the S-191 and S-154, as well as in the vicinity of the S-71 and Fisheating Creek Basins. To do this we assume that all of the inflowing water, minus the spillover amount (which is not treated), is released at the outflow with a phosphorus concentration of 40 ppb. The results are as follows:

Basin	Percent of Water Treated	Flow-weighted concentration (ouflow + spillover, ppm)	Current Load (tons/yr)	Load with RaSTA (tons/yr)
S-191	98%	0.05	94	8
S-154	96%	0.07	23	2
Pool D & E	**	**	**	**
S-71	81%	0.06	32	11
Fisheating Cr.	81%	0.06	61	20
Totals:			**210**	**41**

** as indicated in the text, better data are needed to calculate flows for these basins

In summary, RaSTAs in S-191 and S-154 could reduce phosphorus loads to the lake by roughly 110 tons/yr, and additional RaSTAs in the vicinity of the S-71 basin and Fisheating Creek could reduce loads by another 60 tons/yr. These estimates do not include the additional load reduction that could be achieved by RaSTAs in the S-65D-E basins. Detailed planning for the location and construction of RaSTAs should begin as soon as possible.

Because the RaSTAs will be constructed in locations that are not likely to accrue peat (i.e., not develop a stable long-term storage pool for phosphorus), the plans should give careful attention to RaSTA operations and maintenance. Maintenance options should consider innovative approaches for harvesting phosphorus from the systems that might offset operational costs, including for example the production and harvesting of fish and/or aquatic plants. In large reservoirs, the production of sterile triploid bighead and silver carp have been used with great success to remove phosphorus from the water (Xie 1996). This approach might reduce the size of STAs required to attain an outflow concentration of 40 ppb. In addition, jobs, income, and revenue would be created if the fish were harvested and sold as a marketable product. A preliminary estimate indicates that with the RaSTA sizes given above, approximately 5 million pounds of fish could be produced per year, with a value of 6 million dollars. In addition, as much as 50 tons of phosphorus might be removed from the RaSTA systems per year. Under this option, however, the potential impacts of non-indigenous species on nearby natural ecosystems must be considered.

By using the reservoirs as a location for the culturing of economically or environmentally useful plants (e.g., sources of native plants such as bulrush, peppergrass, and eelgrass for transplant into lakes where habitat restoration projects are occurring), additional benefits could be realized. This could potentially remove some phosphorus from the systems and provide additional jobs, income, and revenue to offset project operational costs.

RECOMMENDATION – Intensify Control of Phosphorus Sources in the Watershed.

To ensure maximal effectiveness and longevity of RaSTA systems and bring to a halt the continued buildup of phosphorus in the watershed, intensified programs to control phosphorus sources must accompany the construction of the regional treatment facilities. In recent decades a number of programs have been implemented in the watershed of Lake Okeechobee to control phosphorus sources. The effectiveness of each program should be carefully evaluated, and where necessary, improvements made in order to ensure that phosphorus sources are being adequately controlled. The following is a summary of existing programs.

The Taylor Creek Headwaters Project and the Taylor Creek-Nubbin Slough Rural Clean Waters Program (RCWP). Under these programs, Best Management Practices (BMPs) were implemented that included fencing cows away from streams, animal wastewater disposal on croplands, and utilization of wetlands for nutrient removal. A more detailed description of these programs can be found in Anderson and Flaig (1995). District staff, who regularly visit agricultural lands in the watershed, indicate that a number of fences constructed under the RCWP are in a state of disrepair, and that cattle sometimes are observed in waterways. This represents a source of phosphorus loading to the tributary system that could be easily addressed.

The Florida Department of Environmental Protection (FDEP) Dairy Rule, which required construction of waste collection and treatment systems for barn wastewater and runoff from high-intensity milk herd holding areas. This program led to reductions in the total phosphorus concentration in water exiting dairy lands, and coincided with declines in total phosphorus in basin tributaries (Havens et al. 1996b). There still are a number of dairies, however, where runoff total phosphorus concentrations exceed the 1.2 ppm expected for FDEP permitted sites. An accurate estimate of the phosphorus loading associated with dairies needs to be done as expediently as possible, and if necessary, actions should be taken to reduce their phosphorus loads.

The Dairy Buy-Out Program provided an option for dairy farmers unable to comply with the Dairy Rule. This program led to some reductions in the concentration of total phosphorus in runoff water, but a number of sites have displayed continued high phosphorus concentrations (Havens et al. 1996b). This presumably reflects phosphorus leaching from accumulated manure and/or over-saturated soils. The amount of phosphorus associated with these sites also needs to be quantified, and actions taken to control phosphorus export from sites with particularly high loads.

A regulatory program called the Works of the District (Chapter 40E-61 FAC), implemented by the SFWMD established a numeric phosphorus concentration limit for runoff from non-dairy land uses. The rule codifies concentration limits for phosphorus from non-point sources in the watershed and sets discharge limits for regulated land parcels according to land use (SFWMD 1989). For example, a total phosphorus concentration limit of 0.35 ppm (12-month rolling average) was set for "improved" cattle pastures. The discharge limits established in the Works of the District rule were based on the lake loading target and information about phosphorus assimilation by wetlands and streams between sources and the lake (see Appendix I-C). When land owners do not meet their discharge limit, the District works with them to identify additional measures (e.g., BMPs) that can be taken to reduce the concentration of phosphorus in their runoff water. It recently was estimated (Zhang and Essex 1997) that if all sites presently exceeding their limits were brought into compliance with the rule, there would be a substantial reduction of phosphorus loading to the lake. It is recommended that this be done as expediently as possible.

An Interim Action Plan (IAP) was implemented in 1979 to reduce nutrient loading to the lake from the Everglades Agricultural Area Environmental Protection District (EAA). The objective of the IAP was to divert as much nutrient-rich water away from the lake as possible and direct it southward towards the Water Conservation Areas, while still maintaining flood protection in the EAA. The IAP has exceeded its original goal of 90% reduction in nitrogen loading to the lake from the EAA, and it also resulted in reduced phosphorus inputs. However, water still is pumped from the EAA to the lake during periods of high rainfall when lands in the EAA are threatened by flooding. It is anticipated that ongoing projects related to implementation of the Everglades Forever Act will lead to further reductions in backpumping.

The Issue Team identified a number of phosphorus sources in the watershed that either are not controlled under existing programs, or where new control measures are expected to have large benefits. *A current accounting of watershed phosphorus sources is needed in order to ensure that other significant sources have not been overlooked*.

One effective method for reducing phosphorus export from agricultural sites is the reclamation of isolated wetlands. Wetlands are efficient for trapping phosphorus and a variety of options exist in the watershed for creating them. These options include vegetative flow-ways, on-farm wetland restoration, and riparian easements. Of the total land north of the lake, 18-25% is classified as wetland (National Wetlands Inventory). Approximately 45% of these wetlands have been ditched, in order to drain the land for agricultural use. It may be possible to restore a large number of these wetlands simply by removing or plugging the artificial ditch. The wetlands could function as on-site water storage facilities during periods of heavy rainfall and stormwater runoff. Analyses of SFWMD data indicate that it is during these periods of time when the greatest loads of phosphorus enter the lake, perhaps due to a washout of manure and other phosphorus sources from soil surfaces. Based on the results of SFWMD studies, small on-site wetlands can be expected to remove between 25 and 80% of the phosphorus that they receive. As part of the Critical Projects under the Water Resoruces Development Act, ten small wetlands will be restored on pasture lands north of Lake Okeechobee. The opportunity exists to restore a much larger number of wetland sites, and this effort might be fostered by incentives and funds from federal programs, such as USDA's Conservation Reserve Enhancement Program.

Another promising method for capturing phosphorus in the runoff from agricultural sites and removing it in a manner that has net economic benefits is the use of plant, periphyton, and or fish cultures. In one system (HydroMentia), water is passed through a bed of hyacinth to assimilate phosphorus; the hyacinths are used as cattle feed, with the discharge passed over algal scrubbers. The algae then are used to feed fish that can be sold commercially. Approaches such as this should be evaluated based on their scientific merit and economic viability.

Among the various land uses in the watershed, spreading of residuals (sludge) and manure on pastures is a serious concern both from the standpoint of phosphorus discharges and public health. Some of the residuals are imported from outside the basin, and the extent to which phosphorus, coliform bacteria, and other harmful substances migrate off-site into surface waters is unknown. The Issue Team recommends that the import of residuals and manure from <u>outside</u> the Lake Okeechobee watershed be prohibited. Given the tremendous quantities of phosphorus that already reside in the basin, it is unacceptable to bring additional loads in from other regions. Second, there must be a careful evaluation of the impacts of residual and manure application (generated within the watershed) on surface water quality. Programs to minimize adverse environmental and public health effects should be identified and implemented by the agencies that regulate these sources.

Other large sources of phosphorus input to the watershed must be controlled. A watershed-scale phosphorus budget that quantifies for each tributary basin the imports and exports of phosphorus, including discharges to the lake, should be completed as soon as possible. The most recent budget is 10 years old, and give the changes in land use and phosphorus import practices that have occurred since then, it is not adequate for identifying major areas of concern.

One potentially important phosphorus input that has been identified is water from the Kissimmee Chain-of-Lakes and Lake Istokpoga. Phosphorus loads from these lakes into the Lake Okeechobee watershed have increased during the last decade by approximately 90 tons/yr. Actions should be taken to reduce these phosphorus loads, however, the measures required to accomplish this will depend on the source of the nutrients. The Issue Team recommends that an expert review be carried out in the immediate future to: (1) identify the most probable source of excess phosphorus from the these lakes; (2) recommend the most appropriate management plan for ensuring that the phosphorus concentrations and loads are substantially reduced.

Given that large quantities of highly mobile phosphorus are known to occur in the sediments of tributaries north of the lake, consideration should be given to removing this source. A program was initiated by the SFWMD in 1997 to evaluate the feasibility of reducing phosphorus loads by removing tributary sediments. Funding was obtained from the USEPA's Section 319 non-point source pollution management program. The results of this project indicated that: (1) much of the sediment phosphorus originated within the tributary system, as opposed to coming from agricultural sources; and (2) it was highly flocculent, and readily transported from one location to another, especially during spate events. Thus, despite the large pool of phosphorus contained in the sediments (over 800 tons), its removal by dredging would not (by itself) be a viable option for reducing phosphorus loads to the lake. However, this study did not consider the possibility of constructing sediment "traps" at selected locations, where sediments could accumulate and then be periodically removed at a much higher efficiency. The District will use remaining 319 funds from the sediment removal project to conduct a pilot study to test the utility of this approach.

II. Internal Phosphorus Loading Issue

Because there is a high rate of internal phosphorus loading (from mud sediments to water column) in Lake Okeechobee, phosphorus control programs in the watershed will not result in recovery of the lake unless the internal load also is controlled. Although external phosphorus loads were reduced considerably between the early 1980s and early 1990s, the concentration of phosphorus in the lake water reached a plateau at near 100 ppb in the 1980s and has not declined since (Havens et al. 1996a, Steinman et al. 1999). This reflects a "buffering" effect due to internal sediment loading that is commonly observed in shallow lakes with a long history of excessive external phosphorus inputs (Sas 1989).

The Issue Team considered a number of in-lake measures that have been used with success to reduce phosphorus concentrations in other shallow, eutrophic lakes. Only one of these measures (sediment removal - see below) was considered likely to have a substantial impact on in-lake total phosphorus concentrations. Nevertheless, a brief description of all in-lake measures considered by the Issue Team is provided here.

A. Phosphorus Removal from the Lake by Plant or Fish Harvesting

As indicated above, one approach that has been used to remove excess phosphorus from small shallow lakes is the harvesting of plants. This method may be particularly useful in lakes where a substantial percentage of the ecosystem's phosphorus is tied taken up and incorporated into plant biomass. In the late 1970s, it was recognized that excessive phosphorus levels were a concern in Lake Okeechobee, and it also was known that extensive beds of the exotic plant *Hydrilla* frequently occurred along the western shore of the lake (especially in Fisheating Bay). Therefore, a large-scale experimental study was conducted to investigate whether *Hydrilla* removal could provide an effective way to reduce quantities of phosphorus in the lake ecosystem. The study was conducted by Mote Marine Laboratory (Technical Report #129, Volume 1), under contract with the SFWMD. In this study, 500 acres of *Hydrilla* were harvested from the lake and data were collected regarding the amount of phosphorus removed, the amount removed per ton of plant material, and the operational costs. Consideration also was given to disposal options. The results were as follows.

i. The phosphorus content of *Hydrilla* was approximately 0.03% of wet weight, which is typical of aquatic vegetation in eutrophic lakes. For each acre of *Hydrilla* harvested, approximately 8 pounds of phosphorus were removed from the lake.

ii. The estimated cost of *Hydrilla* harvesting (in 1988 dollars) was estimated to be between $150 and $175 per acre. Therefore, it would cost approximately $40,000 to remove one short ton of phosphorus using this method.

iii. The major issue that arose during the study dealt with toxic metals in the harvested plant material. As is the case for many aquatic plants and algae, *Hydrilla* bio-concentrate toxins from the water column. Mote Marine found lead and chromium in samples collected from the harvesting project, and concluded that the plant material was therefore “not considered to be a marketable product.”

The Issue Team considered these results, along with recent information regarding the size of various phosphorus pools within the lake, which showed that <3% of the lake’s phosphorus occurs in plants, while over 95% occurs in sediments (Steinman et al. 1999). It was concluded that plant harvesting was not an option that should be listed as a high priority strategy for consideration by the Working Group.

The Team also considered the option of fish harvesting as a means to remove phosphorus directly from the lake. This approach also has been used in shallow eutrophic lakes, most recently in Lake Apopka. The approach is particularly effective for improving water quality in shallow lakes where the fish are dominated by benthivorous fish such as gizzard shad or filter-feeders such as bighead and silver carp (Xie 1996). However, fish of this type do not account for a large percentage of the community in Lake Okeechobee. In Lake Okeechobee, on the other hand, the fish community is more strongly dominated by threadfin shad that are plankton-feeders that do not typically interact with the lake’s sediments. There are some benthivores in the lake, and staff at the Florida Fish and Wildlife Conservation Commission (FWC) have considered the amounts of phosphorus removal that could be achieved by fish harvesting. Scovell (1991) noted that from 1976 to 1990, approximately “3.5 tons of phosphorus leave the lake annualy via commercial harvest.” This is a small quantity of phosphorus relative to the >20,000 tons that occur just in the upper 10 cm of lake sediments (Olila and Reddy 1993), and it is small relative to the amount that is delivered to the lake from its tributaries and by internal loading. The Issue Team generally agrees with the conclusion of Scovell (1991) that commercial fishing on the lake is an ongoing activity that can remove relatively small quantities of phosphorus from the lake, but that it will "not save the lake from over-enrichment." Therefore the harvesting of fish is not listed as a high priority strategy for consideration by the Working group.

B. Chemical Treatment of Lake Sediments

We focus now on methods that could be used to address the issue of internal loading from the massive phosphorus pool that exists in the lake's mud sediment zone. One of the most widely used methods for reducing internal phosphorus loading in eutrophic lakes is sediment "inactivation" using chemical agents, which include aluminum sulfate (alum), iron chloride, and calcium hydroxide (Cooke et al. 1993). Chemical agents present certain risks because at high concentrations and certain levels of pH, they can be very toxic to aquatic organisms, including macro-invertebrates that live in the lake sediments, and fish and other organisms that occur in the water column. The concern regarding water column organisms typically is overcome by pumping the chemical directly to the sediment surface. In deep lakes, the material typically remains at this location and interacts biologically only with benthic organisms. In a shallow wind-mixed lake such as Okeechobee, however, the chemical agent will likely be frequently re-entrained into the water column. This increases the risks of toxicity, which are a particular concern for alum. High iron levels in the water column also would present concerns in regard to drinking water uses. Furthermore, the longevity of any beneficial effects of the chemical treatment may be greatly reduced by resuspension, especially if the lake's circulation gyre carries the chemical agent to certain regions of the lake, leaving other sediment regions exposed. Equally important for consideration is the fact that all of these chemical agents are designed to prevent diffusive fluxes of phosphorus from sediments to the water column. In Lake Okeechobee, the primary mechanism of internal loading appears to be resuspension, rather than passive diffusion (Reddy et al. 1995). For these reasons, the issue team has not included chemical treatment of lake sediments as a high priority strategy for consideration by the Working Group.

C. Lake Sediment Removal

RECOMMENDATION – Remove (if feasible) the phosphorus-rich mud sediments from the bottom of Lake Okeechobee in order to reduce internal loading rates.

The Issue Team considers sediment removal to be the only viable long-term option for substantially reducing the internal phosphorus loading rate in Lake Okeechobee. Complete or partial removal of the lake's mud sediments, which appear to be of recent origin (Brezonik and Engstrom 1999), also might expose some of the natural sand bottom that underlies the mud. This could restore a more natural condition to the lake, and result in improved water clarity and associated ecological attributes (e.g., extent of submerged plant beds and their associated fishery). Hence, important benefits beyond phosphorus reductions might be obtained.

Sediment removal, at the scale being considered for Lake Okeechobee (>300 square miles of mud), exceeds by an order of magnitude any sediment removal project ever attempted in the world. Preliminary cost estimates for complete sediment removal cover a wide range (two of three estimates are in excess of $1 billion), and do not include the costs of disposal. Nor do these estimates address the economic, engineering, and ecological issues associated with a project of this nature and scale. Therefore, a step-wise approach is best for addressing the internal loading issue. The project should begin with a detailed feasibility study, performed by a team of independent scientists who have expertise in phosphorus cycling, sediment dredging and disposal, agricultural soil amendments, aquatic ecology, and economics. In conjunction with this study, pilot tests should be done to evaluate the effectiveness of various methods of sediment removal, dewatering, nutrient removal from effluent water, and disposal. If pilot studies are done in an expedient manner, results can be integrated into the feasibility report. After reviewing this feasibility report, the Issue Team will present a summary of the results to the Working Group, which then can recommend whether or not the next phase, a detailed engineering design, should occur. If the Working Group's recommendation is made and accepted, a project timeline will be developed, sources of funding pursued, and complete or partial sediment removal will begin. This step-wise process for dealing with phosphorus loading was endorsed by the C&SF Restudy Alternative Evaluation Team and included in their final report on Planning Alternative D13R.

It is important to note that reductions in the frequency and duration of high lake stage events may facilitate sediment removal. According to water quality data (Maceina 1993, Havens 1997) and hydrodynamic model results (Sheng and Lee 1991), lower lake stages reduce horizontal transport of phosphorus in the lake and focus sediments toward the mid-lake region, where a removal operation could be concentrated. It might be possible to facilitate this process even further by digging a relatively deep "sediment trap" near the center of the lake's sediment deposition zone. This option can be considered in the lake sediment removal feasibility study.

Sediment removal must be done in concert with the programs to control external loading described above. There are two reasons for this statement. First, as noted by Moss et al. (1999) in their recent guide to the restoration of nutrient-enriched shallow lakes, there is little point in doing anything about internal sources of phosphorus unless external sources also are reduced, for ultimately the external sources provide the stocks of those released internally. Second, in the case of Lake Okeechobee, the high turbidity associated with sediment resuspension creates a poor light climate for algal growth. Hence, in the mid-lake region, algal blooms rarely occur despite high concentrations of phosphorus (Phlips et al. 1997). Removal of sediments without a substantial reduction of external loads could produce a lake that still is relatively phosphorus-rich, with clearer water, and conditions that might actually promote expansion of blooms (which now mostly occur in the western near-shore region) across the entire lake basin.

III. Littoral Vegetation and High Water Level Issues

The native littoral vegetation community in Lake Okeechobee has been heavily impacted in recent years by high water levels, and by the expansion of exotic and nuisance plants. These issues need to be addressed in order to ensure maximal recovery of the lake from human impacts.

RECOMMENDATION – Implement programs to control exotic and native plants and minimize the occurrence of damaging high water levels.

Among the exotic vegetation, the greatest threat at present is torpedo grass. It was originally planted in both the watershed and lake as a forage crop for beef cattle, now has replaced native vegetation in 17,000 acres of the littoral zone (Smith et al. 1998). The grass has taken over habitat once dominated by native plants, primarily in higher elevation areas of the northwestern marsh. It now is expanding into areas with a longer hydroperiod, including locations such as Moonshine Bay (in the west-central littoral zone) that provide prime habitat for sport fish, such as largemouth bass, and the federally-endangered snail kite (Bennetts and Kitchens 1997). Torpedograss is considered by experts to be a poor habitat for fish, apple snails (the primary food resource of snail kite), and other wildlife, due to its dense growth form and the severe lack of oxygen in its standing water.

Unless the spread of torpedograss is controlled, restoration efforts on the lake will be incomplete, and several of its key ecological values will be lost. Field experiments are in progress to identify the optimal mix of herbicide, fire, and environmental conditions for killing dense torpedograss stands so that native plants can return. This research will be completed during the next two years, so that an effective program for killing torpedograss could be implemented in 2002. Likewise, efforts also will continue in the eradication of *Melaleuca*, which also has threatened large regions of native littoral plant community. One approach that soon may be used for *Meleleuca* is biological control (using an insect that attacks only this single tree species). No such program exists for torpedograss, and this method of control should be given serious consideration.

Cattail, a plant well known for its linkage with high nutrient inputs in the Everglades Protection Area, occurs as a wide (1-3 mile) "wall" along the eastern border of the littoral zone in Lake Okeechobee. Cattail also extends into the interior marsh along boat trails and natural watercourses. It is difficult to determine the exact cause of cattail expansion in Lake Okeechobee. However, its location (proximal to deeper areas that periodically receive inputs of nutrient-rich water) is consistent with the view that deeper water and enrichment with phosphorus stimulate its growth.

Based on research conducted to date, it has become clear that hydroperiod plays a role in determining the distribution and abundance of both native and exotic plants in the littoral zone (Richardson and Harris 1995). The understanding of hydroperiod effects now is being expanded by more careful observational work (SFWMD, research in progress) and by controlled experiments being conducted by the USACE Waterways Experiment Station, which are focusing on the effects of water depth on torpedograss and spike rush. It also is clear that water level can significantly effect the outcome of herbicide treatment, and that it can facilitate the use of fires as an exotic & nuisance plant control strategy. There is a need for integration of this information, and development of a holistic plan for dealing with the issues of exotic, nuisance, and native vegetation in the lake's littoral zone. The Issue Team recommends that this line of research continue and that the plan be developed as expediently as possible.

In regard to high water levels, one of the impacts that has been observed in recent years is the accumulation of a ridge of organic mud, referred to by scientists as a berm, along the western shoreline. According to biologists at the FWC, who have conducted research on Lake Okeechobee since the 1960s, organic berms are a common feature along the western and northern shoreline. Photographs taken by staff of the SFWMD in the early 1990s indicate that a substantial berm occurred in the vicinity of the Indian Prairie Canal (in the northwest region of the lake). However, the berm was not brought to public attention until October 1998, when scientists noted that the present structure may be one of the largest and most persistent berms in recent history.

Scientists differ in their views regarding ecological impacts of the berm, but agree that its formation is related to high lake stage and wind. Between 1995 and 1999, prolonged periods of lake stage (in excess of 16 ft NGVD and lasting longer than two years per event) occurred. During these high stage events, light penetration to the lake bottom is greatly reduced, resulting in a loss of much of the submerged plant community that once occurred along the western lake shore. Between 1995 and 1999 there also were shorter periods (1-2 months) when lake stages reached 18 ft NGVD. At those times wind-driven waves uprooted large areas of bulrush, an offshore plant that is provides critical habitat for largemouth bass and other sport fish. All of the dead plant material that accumulated from these events, along with a considerable load of mud sediment, was deposited along the western edge of the littoral zone as a berm. Eroded sections of the shoreline cattail wall also may have contributed to the berm. Research conducted by SFWMD staff in 1998-99 indicate that the berm is dynamic, with large sections periodically forming and disappearing into the deeper waters of the lake. However, large reaches of the shoreline, in the vicinity of Kings Bar and the northwest shore between Indian Prairie canal and Pierce canal, have a relatively conspicuous and persistent berm. Despite relatively low lake levels during summer 1999, submerged plant beds have not returned to the region just off shore of this berm, where the water has remained turbid. Because the berm has raised concerns from an aesthetic standpoint, hinders navigation of sportsmen into the marsh, and may be affecting local water quality (as a possible source of turbidity), the Issue Team recommends that it be removed at the earliest possible opportunity. It must be recognized, however, that unless actions are taken to substantially reduce the occurrence of high lake stage events, future berms can be expected to form.

There also is concern among sport fishermen and commercial fishing guides regarding the loss of submerged plant beds in the lake, and possible declines in the sport fishery (black crappie, in particular). Several public meetings have been held, and a group of fishermen recently formed an organization called the "Friends of Lake Okeechobee," with over 80 members to date. In response to the public concerns about the vegetation losses and berm formation, staff at the FWC proposed a small-scale habitat restoration project. It calls for clearing out large areas of cattail along the littoral edge, followed by planting of native species (eelgrass, peppergrass, pondweed and bulrush) considered to be good spawning habitat for the sport fishery. If funding is obtained, a small-scale pilot project will occur in 1999-2000, and if the results are positive, a larger-scale effort could be undertaken in the future. The Issue Team agrees with this pro-active effort. However, it also must be recognized that the project is not intended as a long-term "fix" for the lake, but rather, it is a necessary interim solution, until lower lake stages can be achieved and natural beds of offshore vegetation re-established.

Alternative D13R of the C&SF Restudy provides the structural and operational features necessary to reduce the frequency, duration, and magnitude of high lake stage events in Lake Okeechobee. Recent model runs to evaluate benefits of plan components built up to 2010 indicate that even at that point, there will be some reduction in extreme and prolonged high lake stages. In the interim, the occurrence of high lake stages could be reduced by implementation of the climate-driven WSE regulation schedule, which offers considerably more operational flexibility than the existing schedule 25.

IV. Summary of Watershed and Lake Issues and Strategies

Issue*: *Excessive Phosphorus Loading

Phosphorus loading is far in excess of the amount considered acceptable for a healthy Lake Okeechobee ecosystem.

***Strategies*:**

1. Construct RaSTAs to attenuate peak flows of water to the lake and to reduce concentrations of phosphorus in that water. Small scale "pilot" STAs are being proposed as the major part of the Critical Project under the Water Resources Development Act. Information on phosphorus processing by these pilot wetlands will facilitate the optimization of large-scale RaSTA systems.

2. Develop a phosphorus budget for the watershed that accounts for all imports and exports, including loading into the lake. This budget will allow for a better identification of major problem areas that should receive priority attention.

3. Review and improve existing programs to control phosphorus discharges in the watershed, to ensure that all regulated sources meet establish discharge concentration targets (Works of the District) or technology-based performance goals (FDEP Dairy Rule). Included under this strategy are: evaluation of the effectiveness of existing applied technologies and their management plans, evaluation of whether numeric

discharge limits should be applied to Dairy operations, evaluation of whether existing numeric discharge limits should be modified, and re-evaluation of the methods whereby numeric discharge limits are established from loading targets and watershed assimilation coefficients.

4. Develop a plan to ensure that new land uses in the watershed do not result in increased phosphorus loads to the lake.

5. Prohibit the import of residuals (sludge) and animal manure from outside the Lake Okeechobee watershed, and evaluate the impacts of the land application of residuals and manure from within the watershed on water quality.

6. Develop and implement measures to control phosphorus inputs from tributary sources that previously (SFWMD 1997) were designated as “uncontrollable.” In particular, consider measures to control phosphorus discharges from the Upper Kissimmee Chain-of-Lakes and Istokpoga, because those discharges have increased dramatically in the last decade.

7. Reclaim isolated wetlands on pasture lands in order to attenuate peak flow of water, remove phosphorus, and provide additional habitat for wildlife. This strategy is being proposed as a Critical Project under the Water Resources Development Act. There may be an opportunity to restore a substantially larger number of wetland sites than the 10 being proposed under the Critical Project.

8. Implement additional management practices on beef cattle ranches that maximize phosphorus reduction, based on results from the ongoing Agroecology Research Project and recommendations from earlier studies (e.g., ensuring that all waterways are adequately fenced to prevent access by cattle) and the BMP document prepared by the Florida Cattlemen’s Association entitled “Water Quality BMPs for Cow-Calf Operations in Florida.”

9. Evaluate, and implement if feasible, sediment traps in tributaries, coupled with periodic removal of the phosphorus-rich material.

10. Evaluate whether routine cleaning of canals and ditches is a significant source of phosphorus loading to the lake. If it is, develop and implement a management plan to ensure that the cleaning does not result in large phosphorus discharges.

11. Evaluate alternative nutrient reduction treatment technologies, such as fish production facilities, based on their scientific rigor and economic viability.

12. Modify the watershed monitoring program so that it can quantify phosphorus loading at various scales, including total loading to the lake, loading from tributary basins, and loads from large land areas. The latter will be required to evaluate the effectiveness of any additional BMPs or compliance with new rules, should they be developed.

Issue*: *Internal Phosphorus Loading

Internal phosphorus loading, from sediments to the overlying water column, must be controlled or the lake will not respond in this century to reductions in the external loading.

Strategy:

1. Implement a lake sediment removal feasibility study, and if it is deemed feasible, carry out complete or partial removal of the phosphorus-rich mud sediments from the lake.

Issue*: *Littoral Vegetation and High Water Levels.

The lake's littoral zone, which provides critical habitat for fish and wildlife (including federally endangered species), has experienced a dramatic expansion of exotic and nuisance plants that are displacing native vegetation. The near-shore region has lost most of its submerged plant community due to high water levels, and a ridge of organic material has accumulated along the western lake shore.

Strategies:

1. Develop and implement a program, using herbicide and fire, which can effectively kill dense stands of torpedograss and allow native plant communities to return to the affected areas. Prioritize the research conducted at the State's new Invasive Exotic Aquatic Plant Quarantine facility, to include the evaluation of the use of biological control agents to kill torpedograss.

2. Continue the District's *Melaleuca* eradication program and research in further biological controls.

3. Develop a comprehensive management plan for control of all exotic and nuisance plants within the lake.

4. Remove the berm and evaluate whether any additional management actions (e.g., replanting of native vegetation) will be needed to bring about re-establishment of submerged plant communities along the western shore.

5. Use the operational flexibility provided by the WSE regulation schedule and components of the C&SF Restudy Project to reduce the occurrence of damaging high lake levels.

V. Funding and Cost-Sharing Opportunities

Critical Projects

Under the Water Resources Development Act of 1996, it is stated that: “if the Secretary, in cooperation with the non-Federal project sponsor and the Task Force, determines that a restoration project for the South Florida ecosystem will produce independent, immediate, and substantial restoration, preservation, and protection benefits, and will be generally consistent with the conceptual framework described in paragraph (1)(A)(ii)(II) of the Act, the Secretary shall proceed expeditiously with the implementation of the restoration project.” The Lake Okeechobee Water Retention Critical Project was ranked #10 on the list and is currently being developed. Estimated costs are $14,500,000. Action Plan strategies, including on-site wetland restoration and pilot STA projects are covered by this Critical Project.

Comprehensive Review Study (Restudy)

In 1992 Congress authorized a Comprehensive Review Study (Restudy) of the C&SF Project. The purpose of the Restudy is to develop modifications to the Central and Southern Florida Project to restore the Everglades and Florida Bay ecosystems while providing for the other water-related needs of the region. The Restudy is currently in the feasibility phase and is jointly funded by the Corps of Engineers and the South Florida Water Management District. The Study is being accomplished by an interdisciplinary, multi-agency team, from a number of Federal, State, Tribal, and local government agencies. The Restudy will result in a Comprehensive Plan that will be submitted to Congress by July 1, 1999. The project is being cost shared 50/50 with the project's non-Federal sponsor, the state of Florida and the South Florida Water Management District (SFWMD). Action Plan strategies, including basin-scale RaSTAs and regional water storage facilities (ASR wells and reservoirs) are included in the Restudy Plan.

Environmental Quality Incentives Program (EQIP)

EQIP was established by the 1996 FACTA Act as a new program to encourage farmers and ranchers to adopt practices that reduce environmental and resource problems. Half of the available funds for EQIP will be targeted at practices relating to livestock production. EQIP must be carried out to maximize environmental benefits provided by the program per dollar expended. During 1996-2002, USDA will provide technical assistance, education, cost sharing, and incentive payments to producers who enter into 5 to 10-year contracts specifying EQIP conservation plans. The program will be available to farmers and ranchers who own or operate land on which crops or livestock are produced including cropland, pasture, and range land. EQIP conservation plans will indicate changes farmers will make to cropping systems, grazing management, manure, nutrient, pest, or irrigation management, and/or land use changes to improve soil, water, and related natural resources including grazing lands, wetlands, and wildlife habitat.

Producers that implement land management practices (e.g. nutrient management, tillage management, grazing management) can receive technical assistance, education, and incentive payments. Producers that implement structural practices (e.g. animal waste management facilities, terraces, filter strips) can receive technical assistance, education, and cost sharing of up to 75 percent of the projected cost of the practice(s). However, large confined livestock operations, subject to definition by USDA, are not eligible for cost sharing to construct animal waste management facilities. An evaluation and selection process will be used to target priority project areas and specific problems within those areas in order to maximize environmental benefits per dollar expended. Program funding for EQIP will be $200 million annually through 2002 except for fiscal year 1996 when funding is $130 million. In general the total amount of cost-share and incentive payments paid to a producer under EQIP may not exceed $10,000 for any fiscal year or $50,000 for a multi-year contract. However, USDA may pay a producer more if it is determined it to be essential to the purposes of the program.

Conservation Reserve Enhancement Program (CREP)

The CREP program is a State/Federal conservation partnership program targeted to address specific State and nationally significant water quality and wildlife habitat issues related to agricultural use. The program uses financial incentives to encourage farmers and ranchers to voluntarily enroll in contracts of 10 and 15 years in duration to remove lands from agricultural production. These lands will be converted to riparian buffers, re-hydrated wetlands and newly created wetlands to address agricultural stormwater sheet flow before it impacts water bodies. CREP cost shares the implementation of these BMP's with both State and Federal participation. CREP pays an annual rental rate based on the rental value of the land. CREP also pays 50% of the costs of establishing buffers along rivers, streams, lakes, and canals, creating new wetlands and up to a 75% costs share for restoring the hydrology and creation of wetlands. CREP delineates criteria for enrolling land in a particular area based on location, characteristics and the kinds of conservation practices that, based on site-specific science, can be demonstrated to be of unusually high environmental value. The Governor's office must submit the State's application. States are expected to contribute at least 20% of the overall costs of the program. Typically that occurs because state funds will be used as the incentive portion of the program. For example, the State may pay to extend the period of conservation beyond fifteen years and to subsidize the non-federal costs of planting of buffers and wetlands restoration and/or provide additional cost-share conservation practices. Both would provide longer conservation benefits while a more complete repayment of restoration costs to landowners that perform restoration. CREP is ideally structured to assist in addressing external loading to the lake through the re-hydration of existing wetlands and creation of vegetated buffers and wetlands.

National Research Initiative Competitive Grants Program (NRI)

The USDA has an Agricultural Systems Program that funds scientific research proposals on an annual basis. Scientists at the University of Florida and SFWMD working on the Beef Cattle Optimization Project at the Buck Island Ranch in Highlands County successfully competed for $215,000 to supplement the on-going research at this site. This grant will fund research in the areas of pasture, livestock, economics, wildlife, and soil science. Additional proposals will be submitted to this funding source in the future.

Wetland Reserve Program (WRP)

The WRP was authorized by the Food, Agriculture, Conservation and Trade Act of 1990, and provides easement payments and restoration cost-shares to landowners who return prior converted or farmed wetlands to wetland condition. Easement payments cannot exceed the fair market value of the land, less the value of permitted uses, such as hunting or fishing leases or managed timber harvest. The enrollment goal of the WRP is 975,000 acres. The WRP is primarily a habitat protection program, but converting cropland back to wetland function also has water quality benefits. Some benefits arise from reduced chemical use on former cropland, but the greatest potential benefits come from the ability of the wetland to filter sediment and agricultural chemicals from runoff and to stabilize stream banks. The Wetland Reserve Program is not targeted on a watershed basis. Water quality benefits would be enhanced by targeting watersheds in greatest need of protection from agricultural runoff.

Wildlife Habitat Incentives Program (WHIP)

The Wildlife Habitat Incentives Program provides financial incentives to develop habitat for fish and wildlife on private lands. Participants agree to implement a wildlife habitat development plan and USDA agrees to provide cost-share assistance for the initial implementation of wildlife habitat development practices. USDA and program participants enter into a cost-share agreement for wildlife habitat development. This agreement generally lasts a minimum of 10 years from the date that the contract is signed.

South Florida Water Management District (SFWMD)

The SFWMD budget for Lake Okeechobee averages over $5,000,000 per year. This includes research, monitoring, planning, regulation and exotic plant control. Research-related activities include: BMP research on beef cattle operations; experimental research to determine why torpedo grass is such an effective invader of the littoral zone; mapping of the sediment coverage and nutrient content in the lake; development and verification of hydrodynamic, water quality, and phosphorus transport models; and nutrient cycling work in the littoral zone, pelagic zone, and watershed. In its fiscal year 2000 budget, the SFWMD will fund projects to (1) intensify activities performed under the Works of the District Program; (2) develop a watershed-scale phosphorus budget; (3) assist the FDEP and USEPA with TMDL development; (4) quantify the rate of phosphorus loading associated with selected dairy sites; (5) quantify the impacts of sludge & manure spreading on water quality; (6) evaluate the feasibility of using sediment traps in tributaries; (7) evaluate the feasibility of lake sediment removal; and (8) reduce water quality model uncertainty. These projects are in addition to the SFWMD's normal funding of programs related to Lake Okeechobee.

United States Environmental Protection Agency (USEPA)

The USEPA has agreed to cost-share ($50,000) the funding of a lake sediment removal feasibility study, to be conducted in 1999-2000 by a team of independent experts under contract with the SFWMD. The SFWMD has provided $500,000 of funds for this project in fiscal year 2000. The project will determine (1) the engineering feasibility of sediment removal; (2) the feasibility of sediment removal without causing ecological impacts to the lake; and (3) the socio-economic implications of sediment removal and disposal.

Florida Department of Environmental Protection (FDEP)

The FDEP will propose in their future budgets funds for cost-shared projects with the District for identifying and implementing programs to eradicate torpedograss from the lake's littoral zone. Funds are required (total from both agencies) in the amount of $150,000 for completing the research to identify the optimal combination of herbicide, fire, and environmental conditions.

Florida Department of Agriculture (FDACS)

Under existing statutes, the FDACS has authority to "develop and adopt by rule suitable interim measures, best management practices, or other measures necessary to achieve the level of pollution reduction established by the Department (FDEP) for agricultural pollution sources in allocations developed pursuant to state law." The FDACS has proposed funds specifically for BMP development in the Lake Okeechobee watershed. This legislative request will be coordinated with the District's WOD and FDEP's Dairy Rule implementation efforts.

National Science Foundation (NSF)

Staff at the SFWMD, in cooperation with staff at MacArthur Agro-ecology Research Center and University of Florida, have submitted a proposal to the ecosystem panel at NSF, requesting $519,200 over three years. This proposal addresses the influence of beef cattle grazing and associated land use on nutrient cycling in subtropical wetlands.

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Appendix I. Re-evaluation of the In-Lake Phosphorus Concentration Goal, the Phosphorus Loading Target, and Methods for Estimating Tributary Phosphorus Assimilation

Although the focus of the Action Plan is on phosphorus load reduction, it is important that lake managers recognize that a primary goal of eutrophication management is to reduce the occurrence of blue-green algal blooms. This is being done in order to protect the lake's drinking water supply, fisheries, and wildlife communities. Phosphorus load reduction is the primary method that has been taken to achieve these goals. It is assumed that by reducing rates of phosphorus input to the lake, water column concentrations of phosphorus will decline, algae will become phosphorus-limited, and blooms will be reduced (James and Havens 1997).

A critical issue is whether the targeted reductions of external phosphorus loads and in-lake phosphorus specified in existing statutes, and the methods used to determine them, are appropriate for achieving algal bloom reduction. Research conducted by scientists at the SFWMD in the last two years has begun to address this issue; proposed research in 1999 will complete the process.

A. In-lake Goal for Phosphorus Concentration

The SWIM Act (Florida Statutes, sections 373.451 and 373.4595) specifies a hydrologically-based phosphorus loading target (Federico et al. 1981) that is designed to achieve a lake-wide average phosphorus concentration of 40 ppb. There were two valid reasons for reconsidering this goal. First, the goal was not based on any empirical relationship between phosphorus concentrations and algal blooms or measures thereof. Second, it considered the lake's pelagic region to be a single, homogeneous zone; today we recognize that this is not the case. The pelagic region has four distinct ecological zones (Phlips et al. 1993) that vary both spatially and temporally in regard to how algae respond to phosphorus, nitrogen, and other limiting factors. The zones also vary in regard to human use. A western near-littoral zone is most highly used for fishing, recreation, wildlife habitat, and municipal water intake; it also is the zone where algal blooms are most strongly correlated with phosphorus concentrations in the water column (Walker and Havens 1995).

Havens and James (1997) re-evaluated the 40 ppb phosphorus concentration goal. They considered how phosphorus concentrations correspond to algal blooms in Florida lakes, took into account the spatial heterogeneity of algal responses to phosphorus in Lake Okeechobee, and considered historical data regarding possible pre-impact phosphorus concentrations in the lake. They found that by using different approaches, goals ranging from as low as 26 ppb (based on a Florida multi-lake regression model) to as high as 92 ppb (based on a set of in-lake regression models) could be derived. They found that using historical phosphorus data, a concentration goal of between 30 and 50 ppb was consistent with restoring the lake's nutrient status to the least impacted condition that has been observed, and that overall, the re-analysis “did not provide strong support” for modifying the existing concentration goal of 40 ppb.

B. Phosphorus Loading Target

Havens and James (1997) also re-evaluated the Federico et al. (1981) phosphorus loading target for Lake Okeechobee. Federico et al. used a modified version of Vollenweider's (1976) eutrophication model to establish rates of phosphorus loading that should result in an in-lake phosphorus concentration 40 ppb. The SFWMD uses this model to calculate target phosphorus loads for the lake. The modified Vollenweider model is a simple set of input-output calculations that assume the following: (i) phosphorus enters the lake along with some volume of water; (ii) some of the phosphorus settles from the water column to the lake sediments, at a rate that depends on lake depth and water residence time; and (iii) some phosphorus and water exits the lake by outflows. Hence, the target loading rate that is predicted to achieve a lake water phosphorus concentration of 40 ppb varies depending on inflow volume, lake depth, and water residence time. Lake managers sometimes indicate that the target load is 397 tons/yr. This is not correct. The 397 value reflects only the average target load during the seven years (1973-79) in which the model was calibrated. Actual yearly targets have varied by more than 100 tons above (wet years) or below (dry years) that value.

There are several concerns about continued use of the modified Vollenweider model for eutrophication management of Lake Okeechobee: (i) The model considers the sediments only as a sink for phosphorus, *via* particle settling. This situation may occur in deep, thermally-stratified lakes in temperate regions, but conditions are more complex in Lake Okeechobee. The shallow lake is polymictic, meaning that the water column does not develop long-term stable thermal stratification. Wind-driven waves frequently resuspend sediment particles and phosphorus into the water column. The sediments do act as a net sink for phosphorus on an annual basis (about 420 tons/yr), but they also represent a gross source of phosphorus input of a magnitude approximately equal to external loads (Olila and Reddy 1993). The modified Vollenweider model does not consider this internal source, and as a result, it dramatically underestimates the external loading rate needed to immediately achieve an in-lake phosphorus concentration of 40 ppb. (ii) The modified Vollenweider model considers losses of phosphorus to the sediments to be a fixed function of depth and residence time. Even if the model was modified to account for internal loads, it could not account for changes over time in the nature of sediment-water phosphorus transport. Havens and James (1997) observed that such changes have occurred, with relatively less net transport of phosphorus to the sediments today than in the 1970s. (iii) The model considers the lake as a "mixed reactor " in which phosphorus is homogeneously mixed into the entire volume of lake water. We now recognize that this is not correct, and that considerable heterogeneity occurs in lake-wide total and soluble phosphorus concentrations (Phlips et al. 1993).

Given these shortcomings of the modified Vollenweider model, James and Havens (1997) recommended that the SFWMD develop and use a “dynamic model that considers major in-lake processes, rather than treating the lake as a black box." In recent years, a complex model of this type has been under development. The WASP/EUTRO modeling framework (James et al. 1997) considers the lake's nitrogen and phosphorus cycles, inorganic suspended solids, sediment-water nutrient exchanges, and has the potential to predict not only total phosphorus concentrations, but also other water quality parameters, including algal biomass and bloom frequency. As such, its uses can extend far beyond setting loading targets and tracking progress towards them.

In the near future, it may be better to use the WASP model for establishing phosphorus loading targets for Lake Okeechobee. Most likely, those targets will (i) be established to attain phosphorus concentration goals for particular lake regions, such as the ecologically-important near-littoral zone; (ii) accompanied by a specified duration component, since the lake clearly will not immediately respond to any level of phosphorus load reduction. Alternatively, the model could provide information regarding the expected number of years until an in-lake goal is attained if we meet some designated external loading rate (e.g., the existing SWIM target load).

C. Tributary Phosphorus Assimilation

When phosphorus is exported from agricultural lands north of Lake Okeechobee into tributary streams and canals, some of the phosphorous is removed (assimilated) from the water before it enters the lake (Reddy and Flaig 1995). Removal can occur *via* physical (settling of particles), chemical (precipitation with calcium or other elements), or biological (plant, periphyton, or microbial uptake) processes. An accurate estimate of assimilation is critical for predicting how changes in land-uses and agricultural management programs in the watershed will affect phosphorus loads to the lake. Furthermore, the assimilation coefficients are the numbers that are used to determine a numeric concentration limit (1.2 ppm for dairy operations) considered necessary to achieve basin concentration target goals of 0.18 ppm.

The existing models of phosphorus transport considers assimilation as follows:

$$P_W = P_R e^{[-(acLc + awLw)]}$$

Where P_W is the concentration of phosphorus (ppb) in tributary flow leaving the watershed; P_R is the concentration of phosphorus (ppb) in water as it leaves a land parcel; Lc is the total transport length (km) of water along stream channels; Lw is the total transport length (km) of water through wetlands; and ac and aw are assimilation coefficients from SFWMD (1989). The values of ac and aw were estimated from routine water quality monitoring data, while stream channel and wetland travel lengths are estimated from areal photography and topographic maps.

Wagner et al. (1996) noted that while this equation is easy to use, it treats phosphorus transport in an overly simplistic manner; i.e., as a function only of transport distance. The authors noted that "the equation is empirical and does not directly represent the processes associated with phosphorus transport (and processing) in stream and wetland systems." As a result, the predictive accuracy of this equation is lower than could be obtained from a more comprehensive model.

To ensure that accurate estimates of phosphorus loading are obtained when considering potential management actions in the watershed, an updated P transport equation will be developed in 1999, with proposed funding in the SFWMD FY99 budget. This equation will be incorporated into an existing watershed phosphorus transport model, and will take into account the physical, chemical, and biological processes affecting phosphorus assimilation along the water course. Because a detailed study of phosphorus transport was recently completed (Reddy and Flaig 1995), it is anticipated that the equation can be developed using available data.

Research also will be done to provide realistic estimates of uncertainty associated with estimates of assimilation, as well as other model predictions described above.